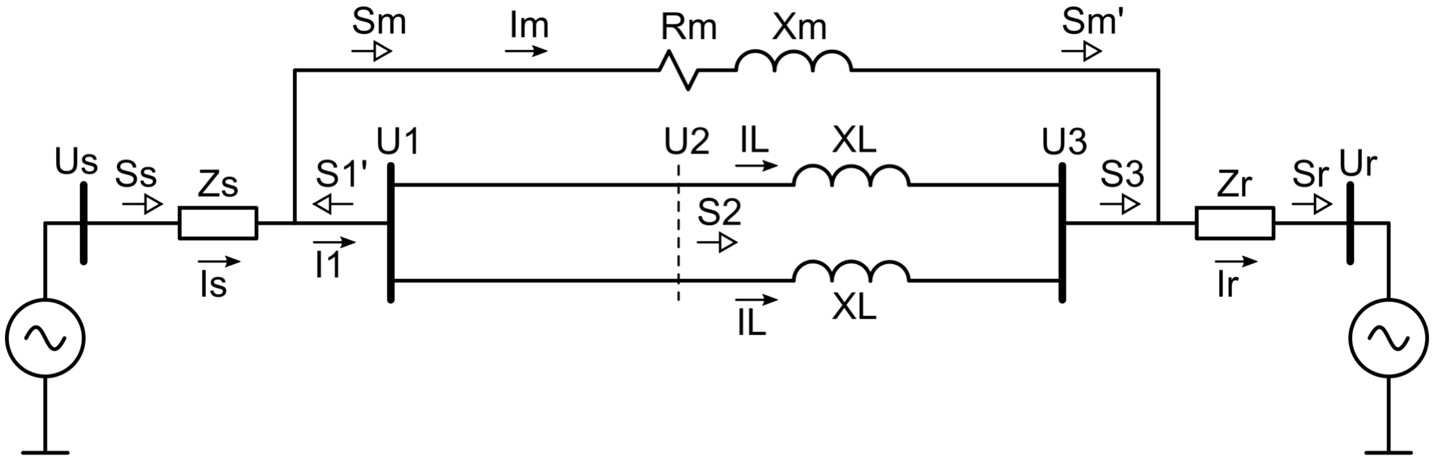
System Before Compensation



$$U_b = U_{LNrms} = \frac{220kV}{\sqrt{3}} = 127kV$$

$$IL_{max} = 1.3kA$$

Objective: Increase power flow through the double circuit line by 200MW…

Voltage values
|Us| = 1.0382 pu, ang(Us) = 18.80 deg
|U1| = 1.0189 pu, ang(U1) = 15.92 deg
|U2| = 1.0189 pu, ang(U2) = 15.92 deg
|U3| = 1.0116 pu, ang(U3) = 13.92 deg
|Ur| = 0.9586 pu, ang(Ur) = 0.00 deg

Current values
|Is| = 1.9301 kA, ang(Is) = 3.55 deg
|I1| = 1.8493 kA, ang(I1) = 3.22 deg
|IL| = 0.9247 kA, ang(IL) = 3.22 deg
|Im| = 0.0815 kA, ang(Im) = 10.96 deg
|Ir| = 1.9301 kA, ang(Ir) = 3.55 deg

Power flows
Ps = 736.70
Qs = 200.90

P1' = -700.45
Q1' = -157.91

P2 = 700.45
Q2 = 157.91

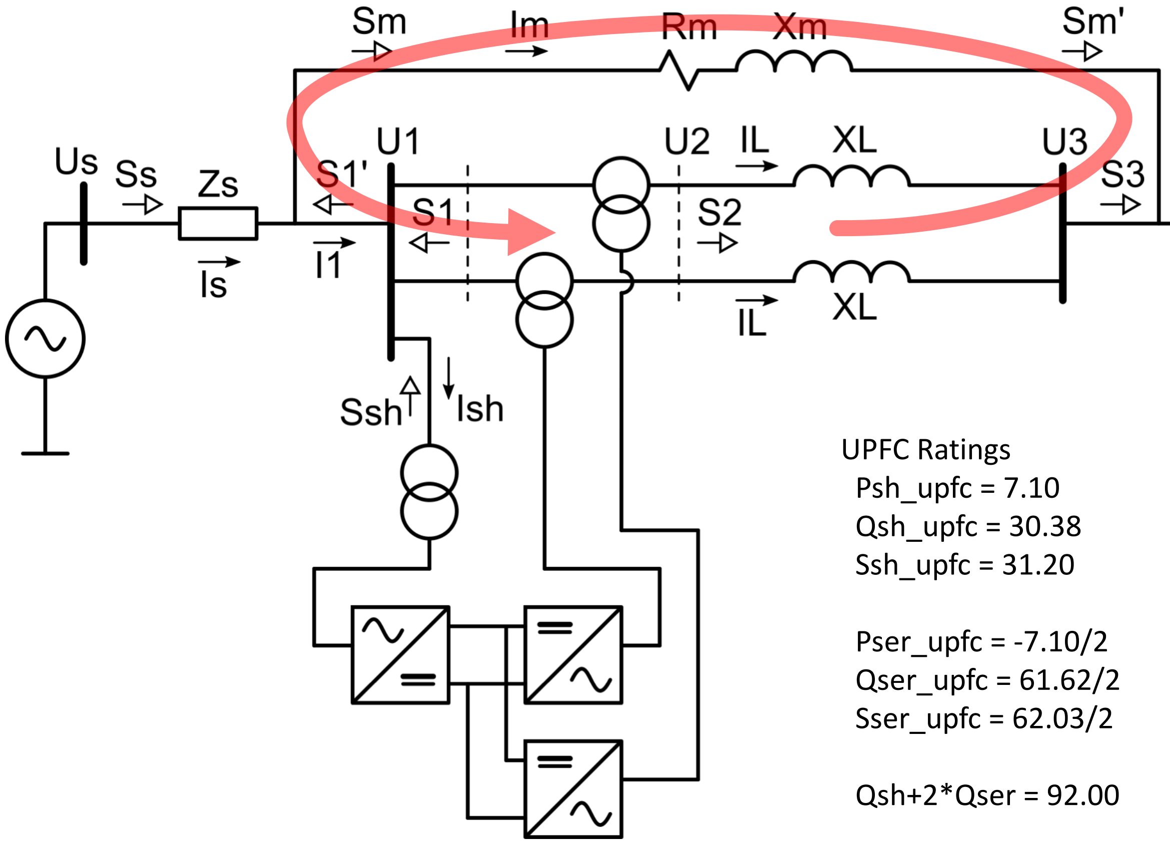
P3 = 700.45
Q3 = 132.39

Pm = 31.52
Qm = 2.74

Pr = 703.70
Qr = -43.61

System Compensated by a UPFC

U3 leads U1 causing loop flow



UPFC Ratings
Psh_upfc = 7.10
Qsh_upfc = 30.38
Ssh_upfc = 31.20

Pser_upfc = -7.10/2
Qser_upfc = 61.62/2
Sser_upfc = 62.03/2

Qsh+2*Qser = 92.00

Voltage values
|Us| = 1.0382 pu, ang(Us) = 18.92 deg
|U1| = 1.0204 pu, ang(U1) = 15.43 deg
|U2| = 1.0252 pu, ang(U2) = 19.28 deg
|U3| = 1.0162 pu, ang(U3) = 16.74 deg
|Ur| = 0.9586 pu, ang(Ur) = 0.00 deg

Current values
|Is| = 2.2834 kA, ang(Is) = 8.01 deg
|I1| = 2.3313 kA, ang(I1) = 8.58 deg
|IL| = 1.1800 kA, ang(IL) = 6.75 deg
|Im| = 0.0532 kA, ang(Im) = -146.01 deg
|Ir| = 2.3128 kA, ang(Ir) = 6.15 deg

Power flows
Ps = 887.00, ΔPs = 150.3
Qs = 170.92

P1' = -900.00
Q1' = -108.00

P2 = 900.00
Q2 = 200.00

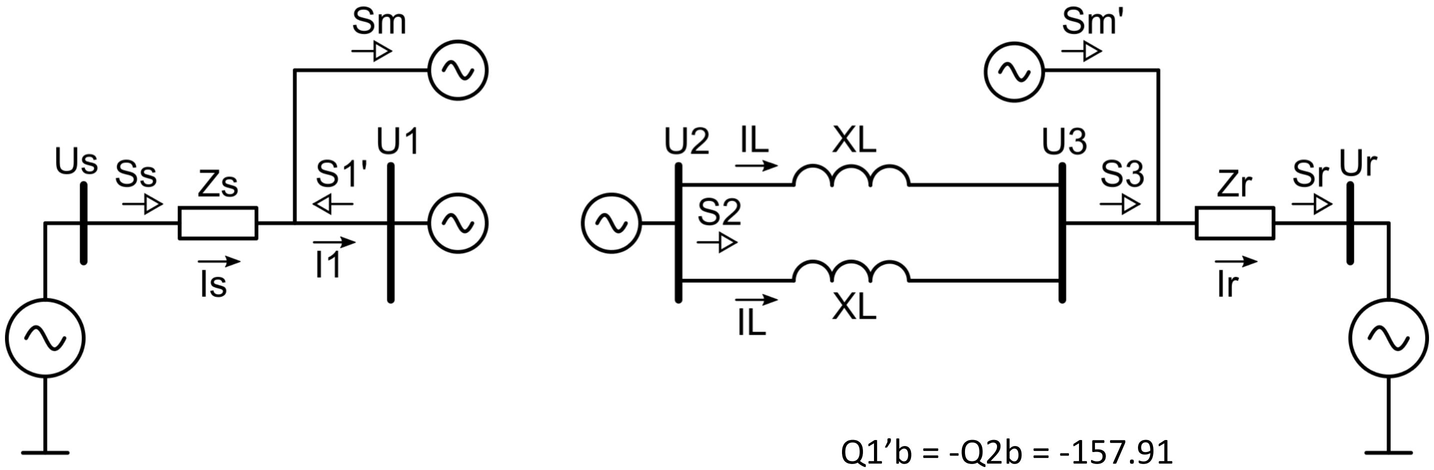
P3 = 900.00
Q3 = 158.44

Pm = -19.62, ΔPm = -51.14
Qm = 6.59

Pr = 839.94, ΔPr = 136.14
Qr = -90.49

Designing the Compensation

System-Centric Approach



Q1’b = -Q2b = -157.91

Q2 = 200, as specified

ΔQ2 = Q2 – Q2b

Q1’ = -158 + (200 - 158) = -116

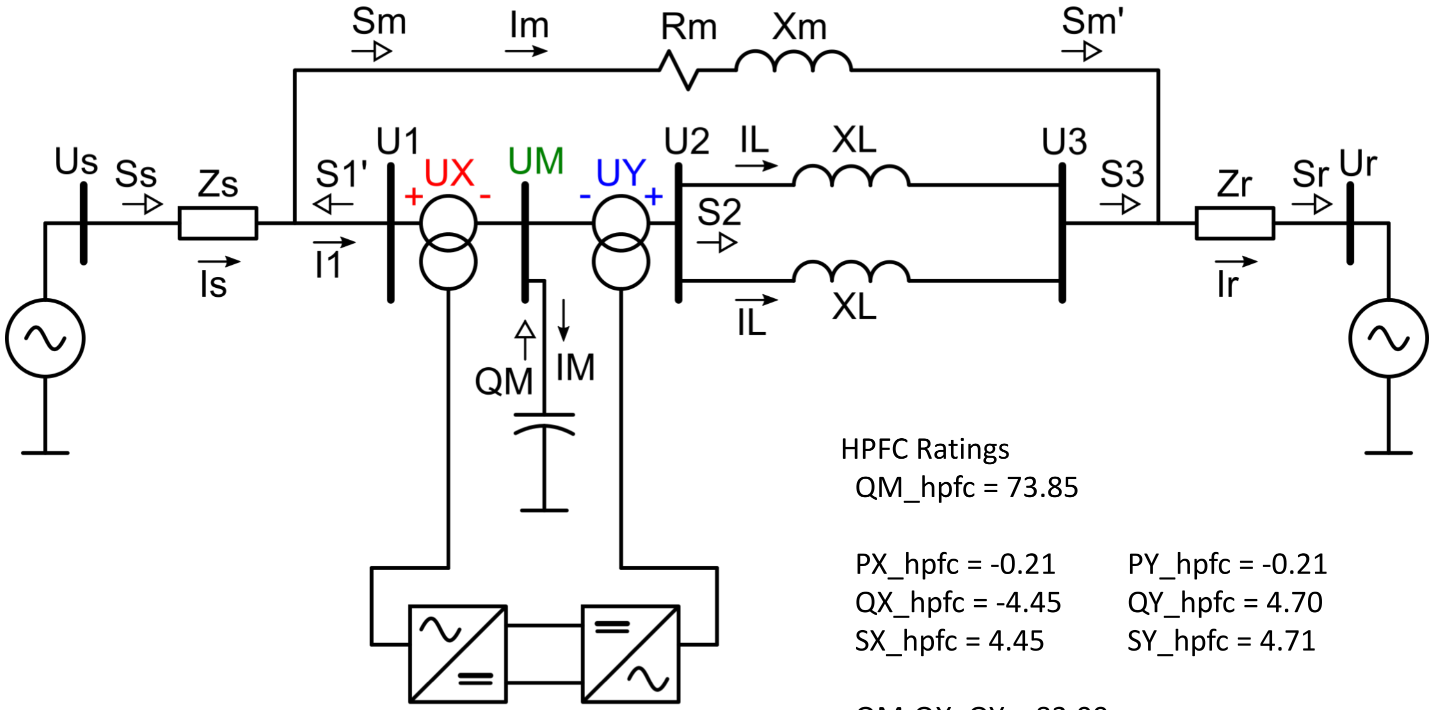
Ps = 934

Adjusted Q1’ = -117

Selecting the operating point

1. Decouple the system at the point of compensation and break parallel paths
2. Use fictitious units to set target flows:
   a) Set S2 (P2+jQ2) to desired values
   b) Set P1’ = -P2
      Set Q1’ = Q1’b + ΔQ2
      (Q1’b = Q1’ before compensation)
   c) Set Sm and Sm’ to their values before compensation
3. Solve load flow to get Ps = real(Ss)
4. Restore the parallel paths, set Ps
5. Adjust Q1’ to balance the ratings of HPFC series converters

System Compensated by an HPFC



$$SX_{hpfc} = 3\ U_X\ conj(I_1)$$

$$SY_{hpfc} = 3\ U_Y\ conj(2I_L)$$

$$QM_{hpfc} = imag(3\ U_M\ conj(-I_M))$$

HPFC Ratings

QM_hpfc = 73.85

PX_hpfc = -0.21
QX_hpfc = -4.45
SX_hpfc = 4.45

PY_hpfc = -0.21
QY_hpfc = 4.70
SY_hpfc = 4.71

QM-QX+QY = 83.00

|IM_hpfc| = 0.1900 kA, ang(IM_hpfc) = 110.14 deg
|UM_hpfc| = 1.0203 pu, ang(UM_hpfc) = 20.14 deg
|UX_hpfc| = 0.0050 pu, ang(UX_hpfc) = -80.26 deg
|UY_hpfc| = 0.0052 pu, ang(UY_hpfc) = 100.45 deg

Terminal voltages:
|Us| = 1.0382 pu, ang(Us) = 23.557 deg
|U1| = 1.0194 pu, ang(U1) = 19.859 deg
|U2| = 1.0211 pu, ang(U2) = 20.424 deg
|U3| = 1.0121 pu, ang(U3) = 17.858 deg
|Ur| = 0.9586 pu, ang(Ur) = 0.000 deg

Current values
|Is| = 2.4179 kA, ang(Is) = 12.538 deg
|I1| = 2.3365 kA, ang(I1) = 12.452 deg
|IL| = 1.1847 kA, ang(IL) = 7.895 deg
|Im| = 0.0814 kA, ang(Im) = 15.008 deg
|Ir| = 2.4502 kA, ang(Ir) = 8.131 deg

Power flows
Ps = 938.94, ΔPs = 202.24
Qs = 182.84

P1' = -900.00
Q1' = -117.00

P2 = 900.00
Q2 = 200.00

P3 = 900.00
Q3 = 158.10

Pm = 31.52, ΔPm = 0
Qm = 2.67

Pr = 886.05, ΔPr = 182.35
Qr = -126.59